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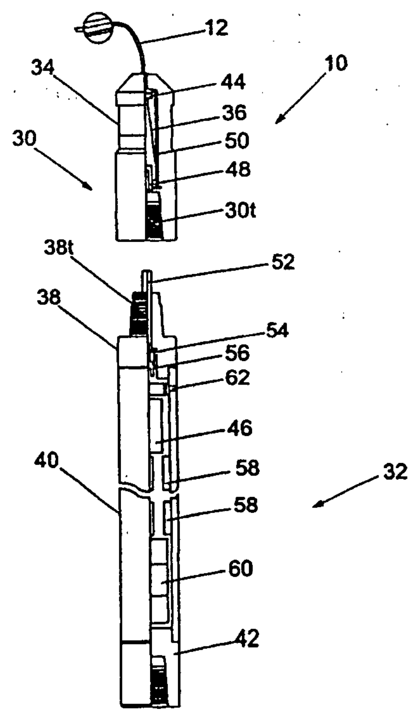
(54) Title: APPARATUS AND METHODS RELATING TO DOWNHOLE OPERATIONS



(57) Abstract: A communication system for use in a wellbore, a downhole tool, and a method includes a transmitter coupled to a wireline, and a receiver located remotely from the transmitter. The wireline is capable of acting as an antenna for the transmitter. The wireline is a slickline, and the transmitter may be associated with, provided on, or an integral part of a downhole tool or tool string. The transmitter typically transmits data collected or generated by the downhole tool or the like to the receiver, which is preferably located at, or near, the surface of the wellbore. The wireline is typically provided with an insulating coating. Also, a distance measurement apparatus and a method for measuring the distance travelled by a wireline includes at least one sensor coupled to the wireline, and the sensor is capable of sensing known locations in a wellbore.

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"Apparatus and Methods Relating to Downhole Operations"

The present invention relates to apparatus and methods relating to downhole operations, and particularly, but not exclusively, to wireline operations.

Wireline is a term commonly used for the operation of deploying and/or retrieving tools or the like using a wire, the wire being one of several different types of construction. For example, slicklines are wires which comprise a single strand steel or alloy piano-type wire which currently have a diameter of around 0.092 inches to 0.125 inches (approximately 2.34mm to 3.17mm) in use, with the possibility of increasing this to 0.25 inches (approximately 6.25mm) in the future.

Wirelines may also be of a braided construction which can also carry single or multiple electrical conductor wires through its core and is typically of a diameter in the order of 3/16 of an inch (approximately 4.76mm) or above. Slick tubing, more commonly known as coiled tubing, is in the form of a continuous hollow-cored steel or alloy tubing which is usually of a diameter greater than the preceding types of wireline.

Wirelines are conventionally used to insert and/or retrieve downhole tools from a wellbore or the like. The downhole tools are typically deployed to perform various downhole functions and operations such as the deployment and setting of plugs in order to isolate a section of the wellbore. It is advantageous and often essential to know the distance of travel of the wireline so that the location of the tool within the wellbore is known.

Wirelines are conventionally stored on a winching unit typically located at the surface in the proximity of the top of a borehole. It should be noted that "surface" in this context is to be understood as being either atmospheric above ground or sea level, or aquatic above the seabed. Although the methods and apparatus employed in wireline operations vary in detail, the wireline is commonly introduced into the wellbore (the wellbore conventionally being cased, as is known) via a series of sheaves or guide rollers. The sheaves or guide

rollers facilitate, in the first instance, a substantially vertical orientation of the wireline. The wireline passes through a substantially vertically-orientated superstructure tube having an internal open-ended bore, the tube being positioned on top of a wellhead. Thus, any downhole tool can be introduced into the wellbore.

The wireline is coupled at its distal (downhole) end to the downhole tool, typically via a part of the tool known as a rope-socket. The rope-socket is conventionally used to provide a mechanical connection between the wireline and the downhole tool (or a string of downhole tools known as a tool string).

The conventional method of measuring the downhole tool depth is to run the wireline against a measuring wheel which is a pulley wheel of known diameter. It should be noted that use of "depth" in this context is to be understood as being the trajectory length of the downhole tool, which may be different from conventional depth if the wellbore is deviated, for example. In order to calculate the distance of travel of the wireline, a number of variable factors must be known. It is a prerequisite that the rotational direction of the pulley wheel, the number of revolutions thereof, the diameter of the pulley wheel and, depending upon the type of pulley wheel (that is, whether a point-type contact or arc for example), the diameter of the wireline, must all be

known before the distance of travel of the wireline within the wellbore can be calculated.

However, with this conventional method for calculating the distance of travel of the wireline, a number of factors can render the calculation inaccurate. The occurrence of wheel slippage, the stretch of the wireline (due to the weight of the wireline itself, and/or the weight of the tool string which is attached thereto), the effect of friction and the well-contained fluid buoyancy all contribute to decrease the accuracy of the tool depth measurement.

In order to improve the accuracy of this conventional depth measurement, it is known to combine the measured tensile load, the known stretch co-efficient of the wireline, and the conventionally measured tool depth as described above, to recalculate the tool depth measurement on a continuous basis (ie in real time) using a processing means, such as a computer or the like.

However, the accuracy of the aforementioned depth measurement correction method relies on an experimentally determined constant (ie the stretch co-efficient of the wireline) and the surface measurements on the wireline. The resulting correction does not include the significant combined effect that well fluid temperature, tool buoyancy and

well geometry have on the accuracy of the depth correction.

According to a first aspect of the present invention there is provided distance measurement apparatus for measuring the distance travelled by a wireline, the apparatus comprising at least one sensor coupled to the wireline wherein the sensor is capable of sensing known locations in a wellbore.

The wireline is typically a slickline.

According to a second aspect of the present invention there is provided a method of measuring the distance travelled by a wireline, the method comprising the steps of coupling at least one sensor to the wireline, the at least one sensor being capable of sensing known locations in a wellbore; running the wireline into the wellbore; calculating the depth of the at least one sensor using any conventional means; generating a signal when the at least one sensor passes said known locations; using the signal to calculate a depth correction factor; and correcting the calculated depth using the depth correction factor.

Preferably, the apparatus includes transmission means for transmitting data collected by the at least one sensor to a receiver located remotely from the apparatus. Preferably, the wireline is capable of acting as an antenna for the transmission means.

The sensor may be coupled to the wireline at any point thereon, or may form an integral part thereof. The sensor is preferably coupled at or near a downhole tool whereby the distance travelled by the tool (and thus its location within the wellbore) can be calculated. Alternatively, the sensor may form part of a downhole tool or the like.

The sensor typically comprises a magnetic field sensor, and preferably an array of magnetic field sensors. The array of magnetic field sensors are typically provided on a common horizontal plane. Alternatively, the sensor may comprise a radio frequency (RF) sensor, and preferably an array thereof. Where an RF sensor is used, the wellbore is typically provided with RF tags at known locations.

The wireline is preferably electrically insulated. The wireline may be sheathed to facilitate electrical insulation. Alternatively, the wireline may be passed through a stuffing box or the like to facilitate electrical insulation and/or isolation.

According to a third aspect of the present invention there is provided a downhole tool comprising coupling means to allow the tool to be attached to a wireline, at least one sensor capable of detecting known locations in a wellbore and generating a signal indicative thereof, and a transmission means capable of transmitting the signal.

There is also provided a method of tracking a member in a wellbore, the method comprising providing a sensor on the member, inserting the member and sensor into the wellbore, obtaining information indicating the position of the sensor in the wellbore, and determining the distance travelled by said member from said sensor information.

The wireline is preferably used as an antenna for the transmission means.

The coupling means typically comprises a rope-socket. The rope-socket is preferably provided with signal coupling means to couple the signal generated by the transmission means to the wireline.

The sensor typically comprises a magnetic field sensor, and preferably an array of magnetic field sensors. The array of magnetic field sensors are typically provided on a common horizontal plane. Alternatively, the sensor may comprise a radio frequency (RF) sensor, and preferably an array thereof. The array of RF sensors are typically provided on a common horizontal plane.

The downhole tool is preferably powered by a DC power supply, and most preferably a local DC power supply. The DC power supply typically comprises at least one battery.

According to a fourth aspect of the present invention there is provided a wireline wherein the wireline is provided with an insulating coating.

The insulating coating is typically an outer coating of the wireline. The wireline typically comprises a slickline.

The insulating coating typically comprises at least one enamel material. The enamel material typically consists of one or more layers of coating whereby each individual layer adds to the overall required coating properties. Additionally, each layer of enamel material preferably has the required bonding, flexibility and stretch characteristics at least equal to those of the wireline.

The enamel material can typically be applied to the wireline by firstly applying a thin layer of adhesive, such as nylon or other suitable primer. Thereafter, one or more layers of an enamel material such as polyester, polyamide, polyamide-imide, polycarbonates, polysulfones, polyester imides, polyether, ether ketone, polyurethane, nylon, epoxy, equilibrating resin, or alkyd resin or theic polyester, or a combination thereof, are preferably applied. The enamel material is preferably polyamide-imide.

According to a fifth aspect of the present invention there is provided a communication system for use in a

wellbore, the system comprising a transmitter coupled to a wireline, and a receiver located remotely from the transmitter, wherein the wireline is capable of acting as an antenna for the transmitter.

The wireline is typically a slickline.

The transmitter is typically associated with, provided on, or an integral part of a downhole tool or tool string, whereby the downhole tool or tool string is typically suspended by the wireline.

The transmitter typically facilitates the transmission of data collected by the downhole tool or the like to the receiver. The transmission means typically comprises a transmitter. The receiver is typically located at, or near, the surface.

Optionally, the communication system is arranged whereby it can facilitate two-way communication between the downhole tool and the receiver. In this embodiment, a transmitter and a receiver are typically located downhole. Additionally, a transmitter and a receiver are also located at, or near, the surface. The transmitter and receiver at the surface and/or downhole may be replaced by a transceiver located downhole and at, or near, the surface.

The transmitter may be coupled to the wireline at any point thereon, or may form a part thereof. The

transmitter is typically coupled at or near a downhole tool whereby the distance travelled by the tool, the status of the tool or other parameters of the tool, can be transmitted to the receiver. Alternatively, the transmitter may form an integral part of a downhole tool.

The wireline is preferably electrically insulated. The wireline may be sheathed to facilitate electrical insulation. Alternatively, the wireline may be passed through a stuffing box or the like to facilitate electrical insulation and/or isolation.

According to a sixth aspect of the present invention there is provided apparatus for indicating the configuration of a downhole tool or tool string, the apparatus comprising at least one sensor capable of sensing a change in the configuration of the downhole tool or tool string and generating a signal indicative thereof, and a transmission means electrically coupled to the at least one sensor for transmitting the signal to a receiver.

The downhole tool is preferably suspended in a borehole using a wireline, and the wireline is preferably capable of acting as an antenna for the transmission means.

The transmitter typically facilitates the transmission of data collected by the sensor to the receiver. The transmission means typically comprises

a transmitter. The receiver is typically located at, or near, the surface.

Optionally, the communication system is arranged whereby it can facilitate two-way communication between the downhole tool and the receiver. In this embodiment, a transmitter and a receiver are typically located downhole. Additionally, a transmitter and a receiver are also located at, or near, the surface. The transmitter and receiver at the surface and/or downhole may be replaced by a transceiver located downhole and at, or near, the surface.

The sensor typically comprises an electric or magnetic sensor which is coupled to the downhole tool wherein a discontinuity of the electric or magnetic connection triggers a signal, or a plurality of signals. These signals can then be transmitted to the surface to indicate the status of the tool. In one embodiment, the sensor may be coupled between a tool string and a downhole tool which is to be deployed into a wellbore, wherein discontinuity of the electric or magnetic connection indicates that the tool has been deployed. Alternatively, the sensor may be coupled to a distal end of the tool string, and the downhole tool which is to be retrieved from a wellbore, is provided with a similar sensor, wherein continuity of the electric or magnetic connection indicates that the tool has been retrieved.

The sensor may also be coupled to part of a downhole tool which changes status during operation of the tool (ie a valve, sleeve or the like) wherein the sensor indicates the status of the part of the downhole tool by a change in continuity.

The sensor may comprise a proximity sensor, magnetic sensor or the like.

The wireline is preferably electrically insulated. The wireline may be sheathed to facilitate electrical insulation. Alternatively, the wireline may be passed through a stuffing box or the like to facilitate electrical insulation and/or isolation.

Embodiments of the present invention shall now be described, by way of example only, with reference to the accompanying drawings in which:

Fig. 1 is a part cross-section of a downhole tool according to a third aspect of the present invention;

Fig. 2 is a schematic diagram of a typical wireline apparatus;

Fig. 3 is an enlarged view of part of the wireline apparatus of Fig. 2;

Fig. 4 is a schematic diagram of a transmitter which forms part of an electronic system for use with the downhole tool of Fig. 1; and

Fig. 5 is a schematic diagram of a receiver which forms part of an electronic system located

at the surface for receiving signals from the downhole tool of Fig. 1.

Referring to the drawings, Fig. 1 shows an embodiment of part of a distance measuring apparatus, generally designated 10. The apparatus 10 includes a slickline 12. Although reference will be made herein to use of a slickline, it will be appreciated that other types of wireline may be used, such as a braided line or cable, coiled tubing or the like. Slickline 12 is typically stored on a reel 14 which forms part of a winching device 16 (Fig. 2), commonly known in the art as a wireline winch unit. The winching device 16 is typically located at the surface. It should be noted that "surface" in this context is to be understood as being either atmospheric above ground or sea level, or aquatic above a seabed.

The slickline 12 is introduced into a cased wellbore (not shown) via a plurality of sheaves or guide rollers, as illustrated in Fig. 2. The sheaves or guide rollers divert the slickline 12 into a substantially vertical orientation. The slickline 12 passes through a vertically-orientated superstructure tube 18 which has an internal open-ended bore, the tube 18 being positioned above a wellhead, generally designated 20.

Referring to Fig. 3, there is shown in more detail a part of the slickline apparatus of Fig. 2. Located at an upper end of the tube 18 is a sheave wheel 22

which guides the slickline 12 from a substantially upward direction through 180° to a substantially downward direction. The slickline 12 then passes through a stuffing box, generally designated 24 in Fig. 3, which typically includes an internal blow-out preventer (BOP) 26.

The slickline 12 enters the tube 18 and continues downward therethrough and into a main BOP 28 and the wellhead 20.

The slickline 12 is coupled at a lower end thereof to a part of a downhole tool commonly known as a rope-socket 30 (Fig. 1). The main function of a rope-socket 30 is to provide a mechanical linkage between the slickline 12 and the tool or tool string. The mechanical linkage may be any one of a plurality of different forms, but is typically a self-tightening means. In the embodiment shown in Fig. 1, the rope-socket 30 includes a wedge or wire retaining cone 34 which engages in a correspondingly tapered retaining sleeve 36.

The rope-socket 30 is also provided with a sealing means which seals around the slickline 12 to provide a seal between the rope-socket 30 and the well environment around the slickline 12. The sealing means typically comprises a seal or gasket 44 which isolates and insulates the interior of the rope-socket 30 from the well environment.

In the embodiment shown in Fig. 1, the rope-socket 30 also provides an electrical coupling between the slickline 12 which is capable of acting as a transmitter/receiver radio frequency (RF) antenna and a downhole tool 32. The tool 32 typically comprises an upper sub 38 which is coupled (typically by threaded connection) to an intermediate sub 40, which is in turn coupled (typically by threaded connection) to a lower sub 42.

The upper sub 38 is provided with a screw thread 38t, typically in the form of a pin, which engages with a corresponding internal screw thread 30t, typically in the form of a box, on the rope-socket 30. These (threaded) connections 30t, 38t allow the rope-socket 30 and tool 32 to be (mechanically) coupled together.

Additionally, the rope-socket 30 is provided with coupling means which electrically couples a metal or otherwise electrically conductive portion of the slickline 12 and a transmitter 46 (a transceiver typically being used to facilitate two-way communication) of the tool 32. The coupling means typically comprises an electrical terminal 48 which is electrically isolated from the body of the rope-socket 30 using an insulating sleeve 50.

The upper sub 38 of the tool 32 is provided with an electrical pin or contact plunger 52 which engages with the electrical terminal 48 within the rope-socket 30. The contact plunger 52 is typically

spring-loaded using spring 54 so that it can move longitudinally (with respect to a longitudinal axis of the tool 32) to facilitate coupling of the rope-socket 30 and the tool 32. A lower end of the plunger 52 is in contact with a main contactor 56 which is electrically coupled to the transmitter 46. This facilitates coupling of signals generated by the transmitter 46 through the plunger 52 and the terminal 48 to the slickline 12, the slickline 12 acting as an antenna for transmitting and/or receiving signals, as will be described.

The tool 32 is also provided with an array of field sensors 58 which are used to detect differences in the magnetic flux at the junctions of, or collars between, successive casing sections which are used to case the wellbore, whereby the location of the tool 32 within the wellbore can be calculated, as will be described.

The tool 32 is preferably powered by a (local) direct current (DC) power source, typically comprising one or more batteries 60. The batteries 60 provide a local electrical power supply for the tool 32. Conventionally, downhole tools are powered using a central conductor of a braided line to transmit electrical power to the tool from the surface. However, there are substantial losses using this method, particularly where the tool is located some distance down the wellbore. In addition, the central conductor of the braided line is typically relatively

small in diameter and thus high voltage drops can be induced. Use of a local power supply (ie the batteries 60) obviates the need for an electrical power connection to the surface.

The tool 32 may include a pressure sensor 62 which is electrically coupled to the transmitter 46 and when present can be used to measure the pressure external to the tool 32.

Referring now to Fig. 4, there is shown a schematic diagram of a transmitter 46 which forms a part of an electronic system located within the tool 32. The batteries 60 provide electrical power to the system in general. On detection of a positive over-pressure to atmospheric level, that is after introducing the tool 32 into the tube 18 (Fig. 2) and opening of the wellhead 20 to allow well pressure to equalise in the tube 18, the pressure sensor 62 activates the magnetic field sensors 58.

The magnetic field sensors 58 may be of the type described in German Patent Application Number DE-A1-19711781.3 (Pepperl + Fuchs GmbH), for example, and are typically mounted within a section of the tool 32 which is at least partially manufactured from a conventional non-ferrous material. This ensures high sensitivity when detecting casing or collar joints.

German Patent Application Number DE-A1-19711781.3 describes use of the sensors 58 in conjunction with a

remnance inducing magnet ring. The wellbore casing sections described therein exhibit a weak magnetic remnance due to the influence of the earth's magnetic field, the difference in the magnetic flux and/or the history of previous well service operations. If the difference in the magnetic flux at the junctions between the wellbore casing sections is insufficiently weak or disorientated, it is advantageous to re-magnetise the casing sections by either running in a separate downhole tool provided with one or more axially orientated magnets prior to commencing the tool detection, or to incorporate one or more such magnets into the tool 32, or the tool string of which the tool 32 forms part.

The plurality of sensors 58 are orientated to preferentially sense the locality and proximity of a collar or casing joint which the tool 32 passes, by detecting the variation or switch in magnetic flux at the junctions or collars between successive casing sections. It is preferred, but not essential, to have the sensors 58 disposed on a common horizontal plane within the tool 32. The latter, in combination with the series connection of the sensors 58 maximise the positive sensing of the collars or casing joints as the tool 32 passes.

When a casing collar or joint is detected, power is supplied to the transmitter 46. The transmitter 46 is located within the tool 32 and is electrically coupled to the batteries 60, the pressure sensor 62

and the magnetic field sensors 58 via suitable electrical connections within the tool 32. Alternatively, the transmitter 46 may be coupled thereto via a system of insulated downhole tool components which provide electrical connections isolated from the well environment, the electrical connections being suitable connectors between the separate downhole sections which make up the complete downhole tool string.

The transmitter 46 may be of a type supplied by RS Components under catalogue number RS 740-449, which is designed to operate in conjunction with a 418 MHz FM transmitter module also supplied by RS Components under catalogue number RS 740-297. However, it should be noted that the transmitter specified above is only an example of one possible transmitter, and that there are many other possible transmitters and frequencies which could be utilised in it's place. The components identified above should be tested for conformity to the particular operational requirements and criteria and for operation in wellbore environments.

The transmitter 46 typically has the facility for address coding (using DIL switch settings 66 in Fig. 4), and data bit settings using either a DIL switch 68 (Fig. 4) or driven by external switches, relay transistors or CMOS logic via an auxiliary connector, designated 70 in Fig. 4). DIL switch 68 is used to switch data channels (ie the four data channels

relating to each one of the sensors 58) on and off, typically using opto-electronic switches 69. Thus, the signal from any one, some or all of the sensors 58 can be set to be transmitted. The output from the DIL switch 66 is typically processed by an encoder convertor 67 which encodes the address coding (as set by the DIL switch 66) into the transmission. RF transmission can be initiated by external contact closure and the provided link on the auxiliary connector 70 (eg, coupling TXEN to ground).

It will be appreciated that with the above described transmission method, the transmitter 46 is not permanently activated and allows only a single transmission upon external contact closure. The duration of the transmission may be altered by changing the values of RT, CT and/or RT2 and CT2 respectively, but is typically in the order of 1 second duration (set by default). The period of transmission may be determined as follows :- 2.2*RT*CT (which changes the interval between transmission in seconds) and 0.7*RT2*CT2 (which changes the duration of the transmissions in seconds).

The transmitter 46 ground connection (ie from any point on the ground connection 64) and RFout connection 65 are electrically coupled to the rope-socket 30 using, for example, electrical connections within the tool 32 (or otherwise as described above) and the plunger 52 and electrical terminal 48

provided on the tool 32 and rope-socket 30 respectively (Fig. 1). These connections are shown schematically in Fig. 4, with the RFout connection 65 being coupled to the slickline 12 which acts as an antenna.

As previously noted, the slickline 12 acts as an antenna for this RF transmission and thus the slickline antenna 12 carries and guides the transmission towards the surface. The RF transmission (ie the electromagnetic (modulated) wave) contains encoded data which is radiated into free-space or any other antenna surrounding medium at or near the tube 18, for example. The precise location of where the RF transmission is radiated into free-space is not important, but it is typically at some point at the surface where the RF transmission can be radiated over a larger area.

Located within the radiation range of the transmitter antenna (ie the slickline 12), for example located at the surface or within the tube 18, is a receiver 80, shown in Fig. 5. Fig. 5 is a schematic diagram of the receiver 80 which forms a part of an electronic system located at or near the surface. The receiver 80 may be, for example, of the type supplied by RS Components under catalogue number RS 740-455, which is designed to operate in conjunction with a 418 MHz FM receiver module 84 supplied by RS Components under catalogue number RS 740-304. However, it should be noted that the receiver specified above is only an

example of one possible receiver, and that there are many other possible receivers which could be utilised in it's place. It should also be noted that the receiver 80 should be matched to the frequency of the transmitter 46. The components identified above should be tested for conformity to the particular operational requirements and criteria and for operation in wellbore environments.

The receiver 80 typically has the facility for address coding (using suitable DIL switch settings on switch 82) to match and pair with the address code of the transmitter 46. The settings of the receiver board jumpers JP1 and JP2 determine the output configuration of the transmission from the tool 32. Jumper JP2 is used to select whether the output is high or low (ie the logic level) which selects whether the output on the four channels out 0 to out 3 on an auxiliary connector 88) are either a logic high or a logic low. Jumper JP1 is used to select whether the output on the channels out 0 to out 3 are latched (ie permanently high or low) or intermittent.

The receiver module 84 receives the signal from the antenna 12 at an RFin connection 86. The signal is then processed in the FM receiver module 84 and output to a decoder 90. The decoder 90 decodes the address coding from the transmission and thus the receiver 80 is only activated when the address of the transmitter 46 matches the address settings of the DIL switch 82 (ie the address of the receiver 80).

The output from the decoder 90 is then fed to a data selector 92 which automatically activates one, some or all of the output channels out 0 to out 3, depending upon which of the four channels have been activated by the settings of the DIL switch 68 on the transmitter 46. The output of the selector 92 is then fed to a seven stage darlington driver 94 which is used to drive the outputs on the auxiliary connector 88. The outputs of the auxiliary connector 88, in particular the outputs out 0 to out 3 are typically coupled to a visual indicator (ie a light emitting diode (LED)) which can be used to allow a user to determine which of the sensors 58 detected a collar or casing joint. Alternatively, or additionally, the outputs of the auxiliary connector 88 may be coupled to a processing means (eg a computer) located at or near the surface for further processing of the data.

It should be noted that although the transmitter 46 is shown coupled to four sensors 58 (Fig. 4) and thus has four channels, the transmitter 46 may be provided with more or less than four channels, depending upon the number and grouping of sensors 58 within tool 32.

In use, the tool 32 is attached to the slickline 12 as described above and introduced into a cased wellbore in a conventional manner. The casing can be of any type, that is, for example, either electrically conductive or semi-conductive ferromagnetic casing, or electrically non-conductive

or non-ferromagnetic casing. The casing string typically comprises of a plurality of casing lengths which are threadedly coupled together, thus making joints (or collars) therebetween.

The tool 32 is lowered into the cased wellbore using the slickline 12. The slickline 12 is typically formed of a metal which has a high yield strength to weight ratio and is capable of supporting the tool 32 (and any other tools which may form part of a downhole tool string). It will be appreciated that the slickline 12 should also be capable of functioning as a monopole antenna.

The slickline 12 is preferably (but not essentially) electrically insulated and/or isolated using a thin outer coating of a flexible, non-conductive insulating material. It is preferred that the material should also be chemical, abrasion and temperature resistant to endure the hazardous downhole environments. The coating is typically an enamel coating.

It should be noted that it may not be necessary to provide an insulating coating on the slickline 12. If a stuffing box or the like is used, the slickline 12 will be electrically isolated by the stuffing box. However, this requires that the slickline 12 does not come into contact with any part of the conductive wellbore which may be difficult in deviated (horizontal) wells or the like. It is thus preferred

that the slickline 12 is coated with an insulating coating to ensure good electrical isolation. It should be noted that coating the slickline 12 with an enamel material also protects the metal wire (from which the slickline 12 is made) against corrosion. In addition, or alternatively, a corrosive chemical sensitive material(s) may be applied as a coating or part thereof on the slickline 12, and this would have the advantage that the presence of corrosive chemicals, such as H_2S or CO_2 or nitrates, in the well would be indicated to the operator when the slickline 12 is removed from the well since the corrosive chemical sensitive material will be transformed; for example, the colour of the corrosive chemical sensitive material may change. In addition, or alternatively, a stress/impact sensitive material(s) may be applied as a coating or part thereof on the slickline 12, and this would have the advantage that mechanical damage to the slickline 12 in the well would be indicated to the operator when the slickline 12 is removed from the well, since the stress/impact sensitive material will be transferred; for example, the colour of the impact/stress sensitive material may change.

The enamel material may consist of one or more layers of coating whereby each individual layer adds to the overall required coating properties. Additionally, each layer of enamel material preferably has the required bonding, flexibility and stretch characteristics at least equal to those of the metal

slickline 12 or coiled tubing. The thickness of the enamel material can vary depending upon the downhole conditions encountered, but is generally in the order of 10 to 100 microns.

The enamel material can typically be applied to the slickline 12 by firstly applying a thin layer of adhesive, such as nylon or other suitable primer. Thereafter, one or more layers of an enamel material such as polyester, polyamide, polyamide-imide, polycarbonates, polysulfones, polyester imides, polyether, ether ketone, polyurethane, nylon, epoxy, equilibrating resin, or alkyd resin or theic polyester, or a combination thereof. The enamel material is preferably polyamide-imide.

The conventional method of measuring downhole tool depth is to run the slickline 12 against the sheave wheel 22. It should be noted that use of "depth" in this context is understood as being the trajectory length of the downhole tool, which may be different from conventional depth if the wellbore is deviated, for example. In order to calculate the distance of travel of the slickline 12, a number of variable factors must be known. It is a prerequisite that the rotational direction of the sheave wheel 22, the number of revolutions thereof, the diameter of the sheave wheel 22 and, depending upon the type of sheave wheel 22 (that is, whether a point-type contact or arc for example), the diameter of the slickline 12, must all be known before the distance

of travel of the slickline 12 within the wellbore can be calculated (and thus the depth of the tool).

However, with this conventional method for calculating the distance of travel of the slickline 12, a number of factors render the calculation inaccurate. The occurrence of wheel slippage, the stretch of the slickline 12 (whether due to the weight of the slickline 12 itself, or the weight of the tool string to which it is attached), the effect of friction and the well-contained fluid buoyancy all contribute to decrease the accuracy of the conventional tool depth measurement.

In order to improve the accuracy of this conventional depth measurement, it is known to combine the measured tensile load, the known stretch co-efficient of the slickline 12, and the conventionally measured tool depth as described above, to recalculate the tool depth measurement on a continuous (ie real time) basis using a processing means (eg a computer).

However, the accuracy of the aforementioned depth measurement correction method relies on an experimentally determined constant (ie the stretch co-efficient of the slickline 12) and the surface measurements of the weight of the slickline 12. The resulting correction does not include the significant combined effect that well fluid temperature, tool buoyancy and well geometry have on the accuracy of the depth correction.

When the tool 32 detects a casing collar or joint during normal slickline operations at downhole tool travelling speed, the tool 32 will process the collected data at normal wireline operational speed using a processing device and signal generator 71 (Fig. 4) which forms part of the transmitter 46. The processing device and signal generator 71 communicates a signal (via a SAW oscillator 73 and 418 MHz band-pass filter 75) indicative of the location of the collar or joint to the slickline 12 which acts as an antenna. At the surface, this signal is received by the surface receiver 80 (Fig. 5). The receiver 80 is coupled to the processing means (eg a computer) located at the surface and the signal from the tool 32 is used to calibrate the conventional measured depth against the known distance between the preceding collar or joint, or other known location. This distance is typically known from an existing record log of the individual casing lengths.

A number of arrays of magnetic field sensors 58 positioned on axially spaced-apart horizontal planes within the tool 32 (as shown in Fig. 1) can be used, each of the sensor arrays having their own channel as described above and being set at known (but not necessarily equal) distances along the longitudinal axis of the tool 32. This allows for increased accuracy of the calibration due to the repeated calibration against the detected collar or joint. It

should be noted that when using multiple arrays of sensors 58, only a single transmitter 46 and receiver 80 need be used as each array 58 will have their own individual channel which can be selected or deselected as required.

However, if the communication system is being used with other sensors within the tool, these other sensors may be coupled to another transmitter and receiver, the other transmitter and receiver including a different address coding. This allows multiple transmissions to multiple receivers 80 from multiple transmitters 46 using only one slickline 12 as the antenna.

The signal from the tool 32 is, for the purpose of the described tool depth measurement calibration, a measure of a known trajectory length of the tool 32 in relation to a detected collar or casing joint end length (casing-section length calibration). This is dependent upon the configuration of tool 32 within the downhole tool or string. Alternatively, the signal is a measure of the trajectory length as travelled by the tool 32 in relation to the detected collar or casing joint as indicated by each separate positive signal from the tool 32 (downhole tool length calibration). For the casing section length calibration technique, the accuracy of the calibration may depend upon the accuracy and completeness of surveyed well details, that is the length of the individual casing sections and the

configuration thereof. For the downhole tool length calibration method, surveyed well details are not necessary.

With the casing length calibration method (hereinafter CLC), the trajectory length or tool depth calibration, as performed by the processing means at the surface, uses the received signal from the tool 32 and references this signal against the conventionally obtained surface measured depth, obtained as described above, and the details of the well. That is, the individual casing length is used to calculate a depth correction factor μ wherein

$$\mu_{CLC} = L_c/(D_2 - D_1),$$

wherein

L_c = casing length;
D_1 = surface depth at the previous casing collar or joint;
D_2 = surface depth at the detected casing collar or joint, where $D_2 > D_1$; and
μ_{CLC} = depth correction factor.

The depth correction factor μ_{CLC} is used by the processing means to correct the conventionally obtained depth over the next downhole tool trajectory casing length.

With the downhole tool length calibration method (hereinafter TLC), the trajectory length or tool depth calibration is performed by the processing means located at the surface, for example. The processing means uses the received signal from the tool 32 and references this signal against the conventionally obtained surface measured depth to calculate a depth correction factor μ. The correction factor μ can be calculated as follows for equidistant sensor spacing (ie constant distance between sensors)

$$\mu_{TLC} = L_u/(D_n - D_{n-1}),$$

wherein

L_u = tool sensor distance constant (ie the uniform distance between the sensors);
D_1 = surface depth at the first tool sensor;
D_{n-1} = surface depth at the previous casing collar or joint;
D_n = surface depth at the detected casing collar or joint, where $D_n > D_{n-1} > D_1$; and
μ_{TLC} = depth correction factor.

The correction factor μ can be calculated as follows for non-uniform sensor spacing (ie non-constant distance between sensors)

$$\mu_{TLC} = L_n/(D_n - D_{n-1}),$$

wherein

L_n = tool sensor distance spacing (ie the non-uniform distant between the sensors);
D_1 = surface depth at the first tool sensor;
D_{n-1} = surface depth at the previous casing collar or joint;
D_n = surface depth at the detected casing collar or joint, where $D_n > D_{n-1} > D_1$; and
μ_{TLC} = depth correction factor.

The depth correction factor μ_{TLC} thus derived can be used by the processing means to correct the conventionally obtained depth over the next travelled spacing between the sensors (either uniform or non-uniform). If the total tool distance (that is the distance between the sensors provided in the tool 32) is less than the individual casing length, the derived multiple-calibrated correction factor μ_{TLC} may be used to correct the conventionally obtained depth related input over the next downhole tool trajectory individual casing length.

It will be appreciated that the depth correction described above need not be performed in real-time. A running history file can be constructed using each surface-received signal from the tool 32 and after completion of a slickline run (downhole tool travel from surface to a depth and return to surface), the history file can be compared against a similar file

derived from the conventional depth measurement technique and the results analysed to interpret and evaluate the downhole tool run objectives and results.

It will be appreciated that the use of a slickline as an antenna is not limited to facilitate an increase in accuracy of tool depth measurements. For example, the conventional method for detecting the status of a downhole tool or tools (that is a tool which is deigned to perform downhole functions such as setting plugs or isolating sections of the wellbore to deploy memory gauges) would be by a differential calculation involving the experience of the slickline operator in conjunction with correlated depth between distance travelled by the slickline (calculated using the conventional technique) and the location of a "nipple" in conjunction with the previously recorded "nipple" depth or tubing tally, or by other means involving physical stresses in the slickline (for example increased/decreased tension in the slickline). A "nipple" is a receptacle in which the downhole tool locates and latches into, or the position in the tubing or casing string for the deployment of the downhole tool to carry out its function.

Once the downhole tool has been deployed or retrieved, the slickline winch operator typically sees a corresponding decrease or increase in the weight of the tool string equivalent to the weight of

the tool, which would be indicative of a successful deployment or retrieval.

However, where the downhole tool is of a marginal weight so as not to show a significant difference in the weight of the tool string once it has been deployed or retrieved, or when circumstances inside the wellbore give a smaller indication than one of those described above (for example an obstruction in the tubing or such like), the status of the downhole tool is derived by conjecture until a time when the function of the tool can be operatively tested or the tool string is returned to the surface.

As will be appreciated, these methods of ascertaining the status of downhole tools are not accurate and rely on the experience of the slickline winch operator, a careful tally of running and pulling weights, and accurate weight indication and depth correlation means. Even when these criteria have all been met, there is no guarantee that the downhole tool has been successfully deployed or retrieved correctly and where downhole tools which rely on the position of sliding sleeves are used, there is no indication of the position thereof until further tests have been carried out.

The present invention facilitates a means to actively identify when a downhole tool has been deployed or retrieved etc by incorporating into the previously described apparatus one or more sensors (eg a

proximity or electrically connecting/disconnecting sensor) which activates the transmission of a signal via the slickline antenna which is indicative of the status of the tool (ie latched, unlatched, engaged, disengaged etc). This would provide a more reliable indication of the tool status in connection with the previously described depth correlation which substantially mitigates the possibility of human error in identifying whether the downhole tool has been correctly deployed or retrieved etc.

When a downhole tool has been deployed, retrieved or otherwise, it is normally the case to use a mechanical force in order to facilitate this deployment, retrieval or otherwise in order to operate a mechanism incorporated in the downhole tool in order to carry out the function of the tool. An example of this would be a running tool which is used to deploy a downhole plug which typically relies on the slickline operator to locate the tool in its downhole position using the conventional depth measurement. Thereafter, either pulling sharply on the slickline or rapidly slackening it induces a hammering effect on the tool whereby a pin (or a plurality thereof) are sheared to allow the tool to engage in a locking assembly, thus disconnecting the tool from the string, or a collar is pulled to retract such an assembly in order to release the tool from the locking assembly thus connecting the tool to the string.

A signal from a proximity sensor or the like can be propagated to the surface using the slickline as an antenna, the signal being received at the surface and causing, for example, a second signal to be transmitted from the surface to a relay provided on the (downhole) tool to electrically or electromechanically operate an automatic locking or unlocking device. This would eliminate the requirement for mechanical hammering to initiate the functioning of the downhole tool.

Another application of the present invention would be during the deployment of downhole tools, a part or parts of the tool itself or the tool string can loosen or be disconnected from the tool or string. This can then require several runs into the wellbore in order to recover the tool or part thereof. This can be a very expensive process.

To overcome this, the tools within the tool string or the parts of the tool themselves can be coupled together either electrically or magnetically wherein discontinuity of the electrical or magnetic connection triggers a signal or a plurality of signals which can be transmitted to the surface to indicate to the slickline operator that such an event is about to occur.

Modifications and improvements may be made to the foregoing without departing from the scope of the present invention. For example, the foregoing

description relates to the use of a slickline as an antenna, but it will be appreciated that it is equally possible to use a braided line or a mono-conducting slickline. Additionally, the pulsed transmission to the surface could be replaced by a continuous type transmission, or alternatively, may be a pulsed or continuous two-way communication between the surface and a tool, using suitable transmitters and receivers (or transceivers) for such communications.

Although the foregoing description relates to the use of a tool which detects the location and passage of collars in a cased wellbore, it will be appreciated that tools exist which are sensitive to non-collared pipe joints.

Additionally, it will be appreciated that the communication system described herein enables the use of a slickline in combination with downhole tools, such as flow meters, pressure, temperature, gravitational, sonic and seismic sensors, downhole cameras and/or optic/IR sensors which have hitherto relied on electric (single- or multi-conductor) braided slicklines for operation.

CLAIMS:-

1. A communication system for use in a wellbore, the system comprising a transmitter coupled to a wireline, and a receiver located remotely from the transmitter, wherein the wireline is capable of acting as an antenna for the transmitter.

2. An apparatus according to claim 1, wherein the wireline is a slickline.

3. An apparatus according to either of claims 1 or 2, wherein the transmitter is associated with, provided on, or an integral part of a downhole tool or tool string.

4. An apparatus according to claim 3, wherein the downhole tool or tool string is suspended by the wireline.

5. An apparatus according to either of claims 3 or 4, wherein the transmitter transmits data collected or generated by the downhole tool or the like to the receiver.

6. An apparatus according to any preceding claim, wherein the receiver is located at, or near, the surface of the wellbore.

7. An apparatus according to any preceding claim, wherein the transmitter is coupled to the wireline at

or near a downhole tool whereby the distance travelled by the tool, the status of the tool or other parameters of the tool, can be transmitted to the receiver.

8. Apparatus according to any preceding claim, wherein the wireline is electrically insulated.

9. Apparatus according to any preceding claim, wherein the wireline is sheathed to facilitate electrical insulation.

10. A method of communication in a wellbore, comprising providing a transmitter coupled to a wireline, paying an end of the wireline and the transmitter into the wellbore, and providing a receiver located remotely from the transmitter, such that the wireline acts as an antenna for the transmitter.

11. A wireline for use in a wellbore, wherein the wireline is provided with an insulating coating.

12. A wireline according to claim 11, wherein the insulating coating is an outer coating of the wireline.

13. A wireline according to either of claims 11 or 12, wherein the wireline comprises a slickline.

14. A wireline according to any of claims 11 to 13, wherein the insulating coating comprises at least one enamel material.

15. A distance measurement apparatus for measuring the distance travelled by a wireline, the apparatus comprising at least one sensor coupled to the wireline wherein the sensor is capable of sensing known locations in a wellbore.

16. Apparatus according to claim 15, wherein the wireline is typically a slickline.

17. Apparatus according to either of claims 15 or 16, wherein the apparatus includes transmission means for transmitting data collected by the at least one sensor to a receiver located remotely from the apparatus.

18. Apparatus according to claim 17, wherein the wireline is capable of acting as an antenna for the transmission means.

19. Apparatus according to either of claims 17 or 18, wherein the sensor is coupled at or near a downhole tool whereby the distance travelled by the tool, and the location of the tool within the wellbore, can be calculated.

20. Apparatus according to any of claims 17 to 19, wherein the wireline is electrically insulated.

21. A method of measuring the distance travelled by a wireline, the method comprising the steps of coupling at least one sensor to the wireline, the at least one sensor being capable of sensing known locations in a wellbore; running the wireline into the wellbore; calculating the depth of the at least one sensor; generating a signal when the at least one sensor passes said known locations; using the signal to calculate a depth correction factor; and correcting the calculated depth using the depth correction factor.

22. A downhole tool comprising coupling means to allow the tool to be attached to a wireline, at least one sensor capable of detecting known locations in a wellbore and generating a signal indicative thereof, and a transmission means capable of transmitting the signal.

23. A downhole tool according to claim 20, wherein the wireline acts as an antenna for the transmission means.

24. A downhole tool according to either of claims 22 or 23, wherein the coupling means comprises a rope-socket.

25. A downhole tool according to claim 24, wherein the rope-socket is provided with signal coupling means to couple the signal generated by the transmission means to the wireline.

26. A downhole tool according to any of claims 20 to 23, wherein the downhole tool is powered by a DC power supply.

27. A method of tracking a member in a wellbore, the method comprising providing a sensor on the member, inserting the member and sensor into the wellbore, obtaining information indicating the position of the sensor in the wellbore, and determining the distance travelled by said member from said sensor information.

28. Apparatus for indicating the configuration of a downhole tool or tool string, the apparatus comprising at least one sensor capable of sensing a change in the configuration of the downhole tool or tool string and generating a signal indicative thereof, and a transmission means electrically coupled to the at least one sensor for transmitting the signal to a receiver.

29. Apparatus according to claim 28, wherein the downhole tool is preferably suspended in a borehole using a wireline, and the wireline is capable of acting as an antenna for the transmission means.

30. Apparatus according to either of claims 28 or 29, wherein the transmitter facilitates the transmission of data collected by the sensor to the receiver.

31. Apparatus according to any of claims 28 to 30, wherein the transmission means comprises a transmitter.

32. Apparatus according to any of claims 28 to 31, wherein the receiver is located at, or near, the surface of the borehole.

33. Apparatus according to any of claims 26 to 30, wherein the apparatus is arranged whereby it can facilitate two-way communication between the downhole tool and the receiver.

34. Apparatus according to any of claims 28 to 32, wherein the sensor comprises an electric or magnetic sensor which is coupled to the downhole tool wherein a discontinuity of the respective electric or magnetic connection triggers at least one signal.

35. Apparatus according to any of claims 29 to 34, wherein the wireline is electrically insulated.

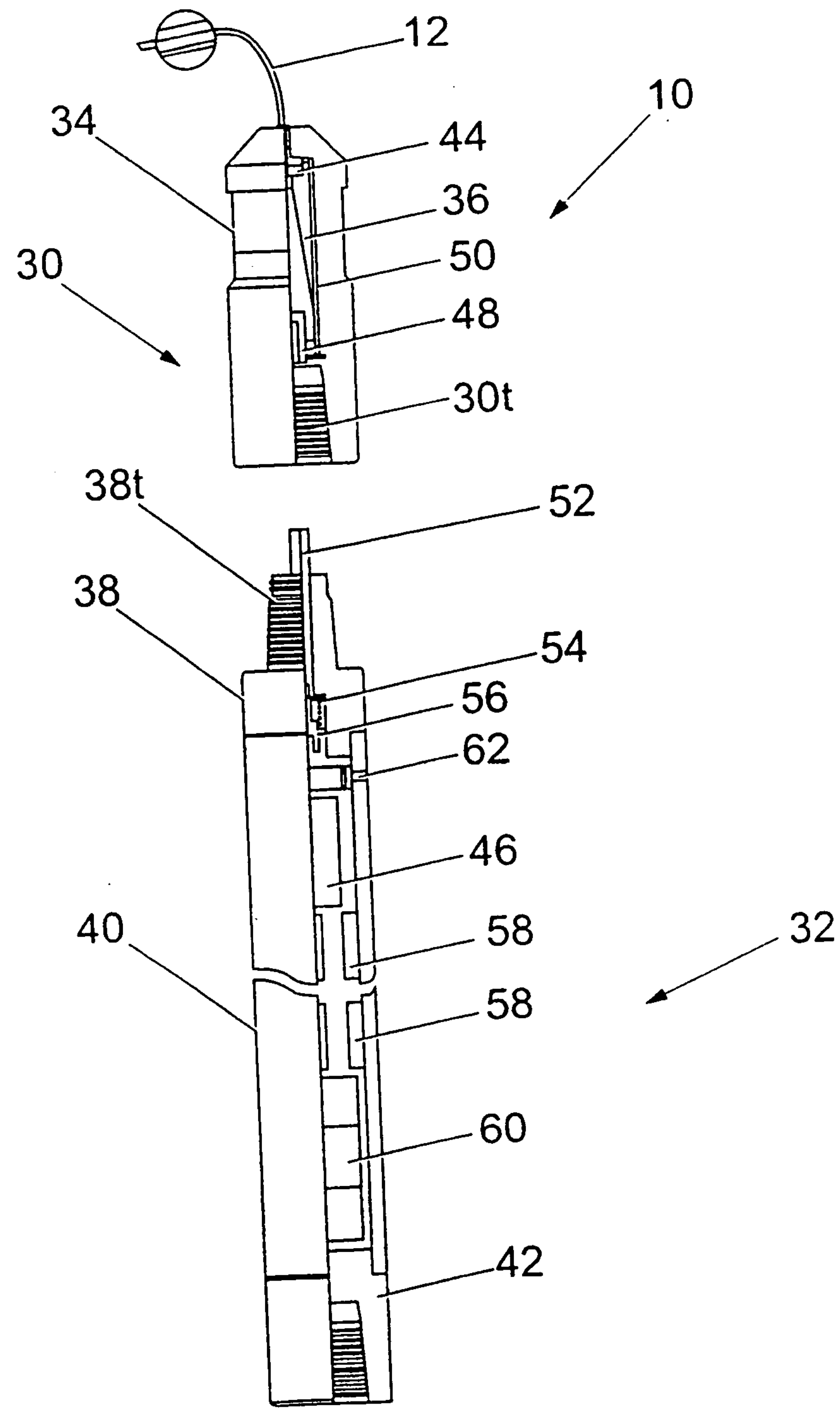

Fig. 1

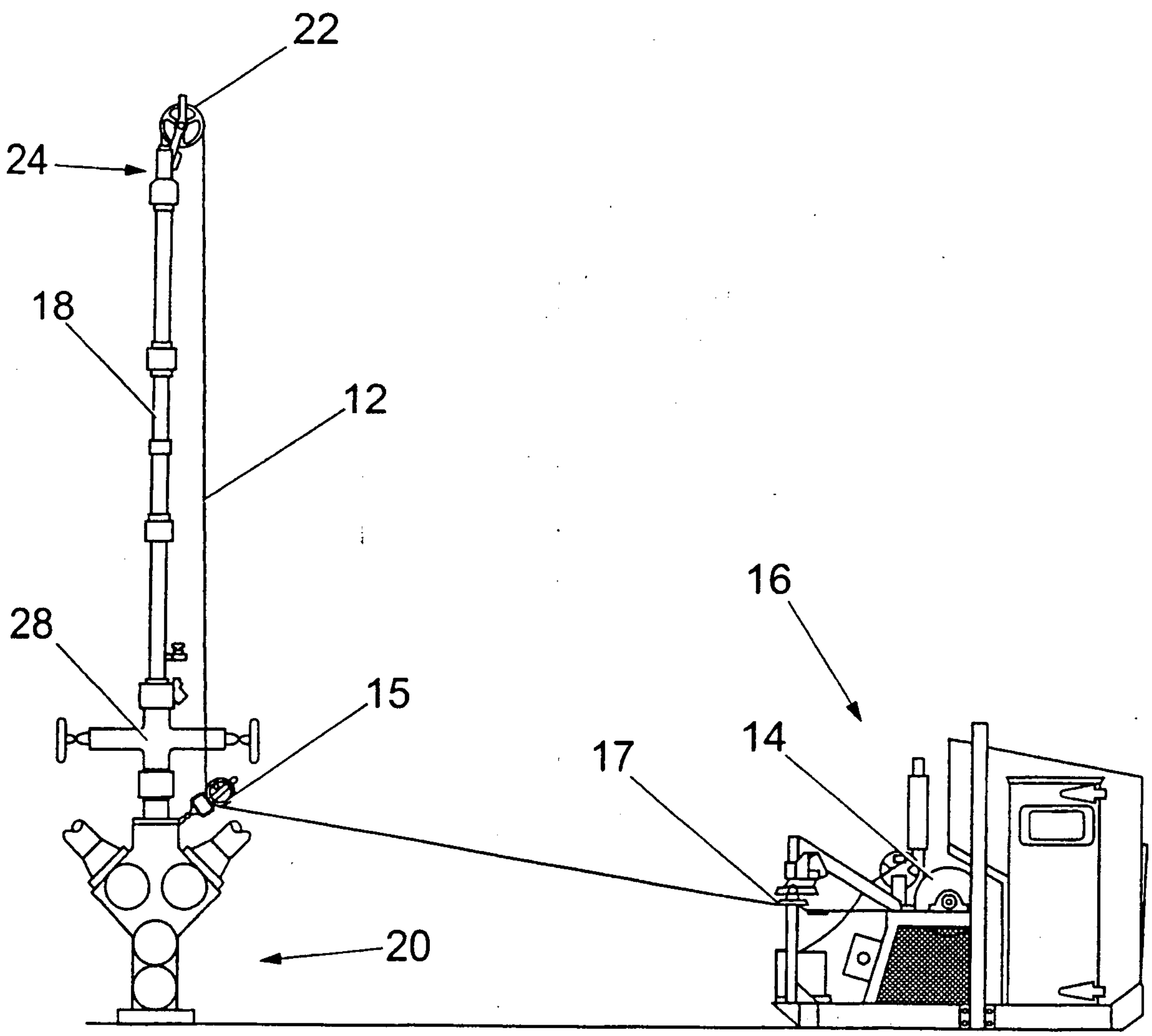

Fig. 2

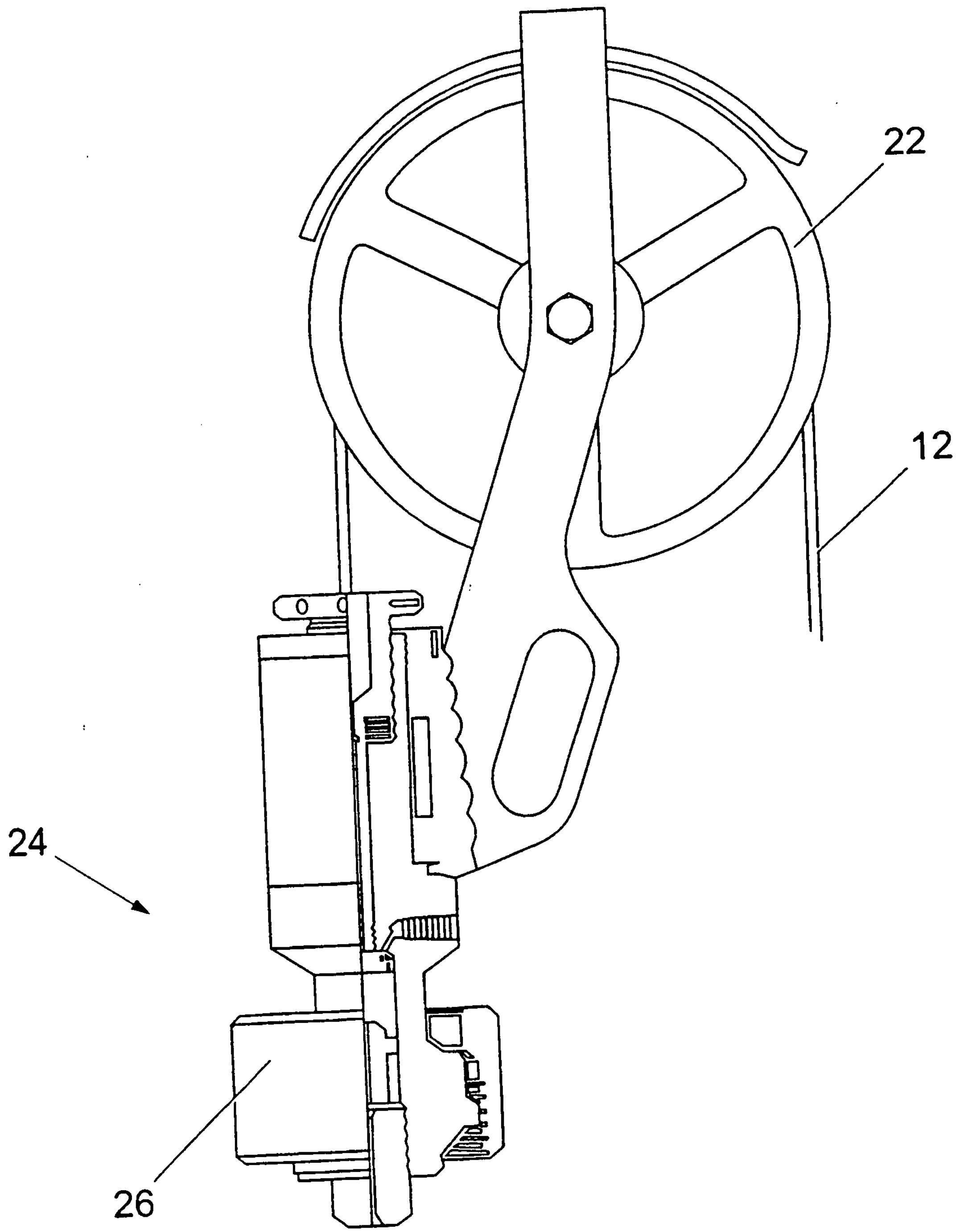

Fig. 3

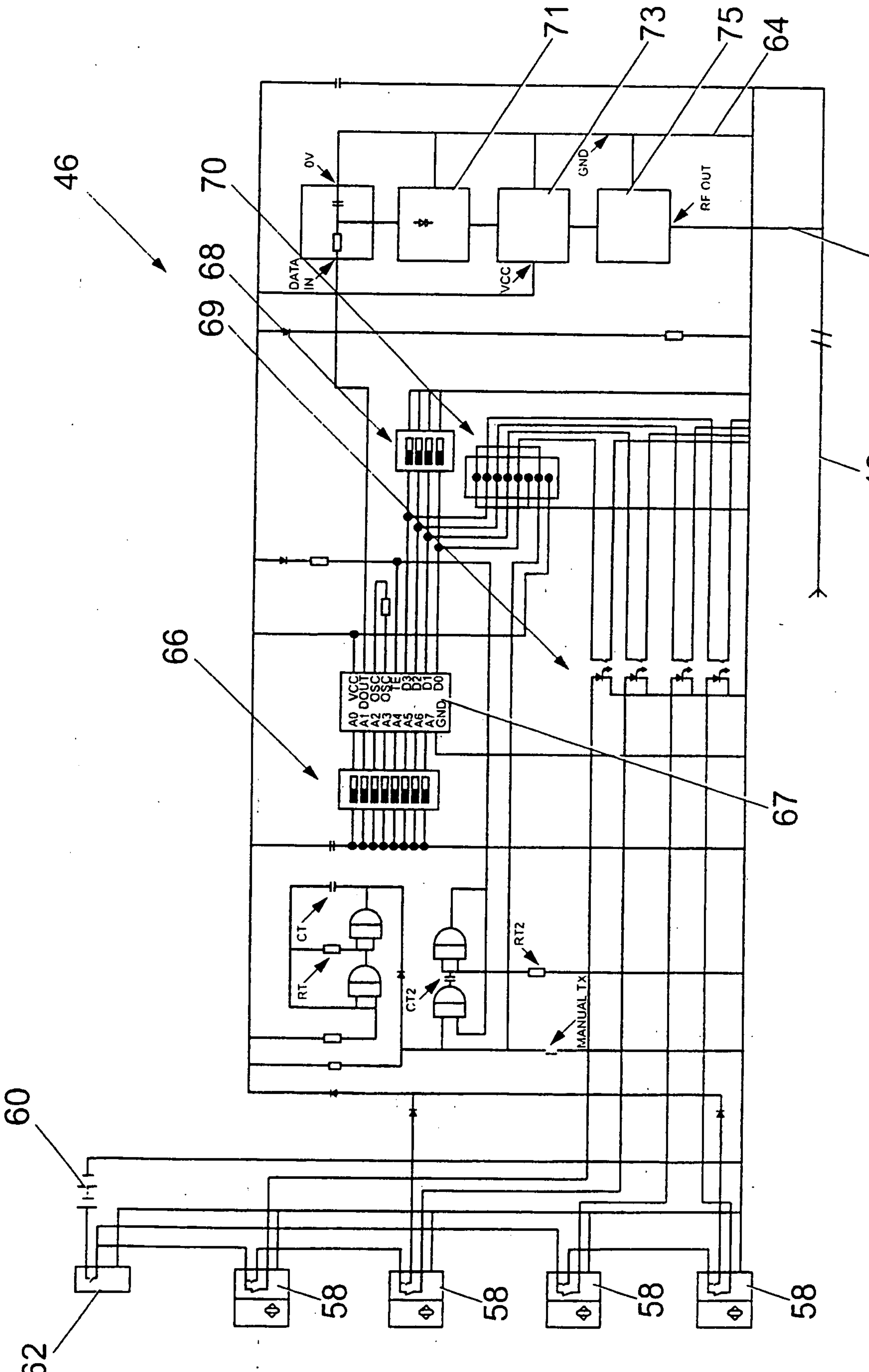
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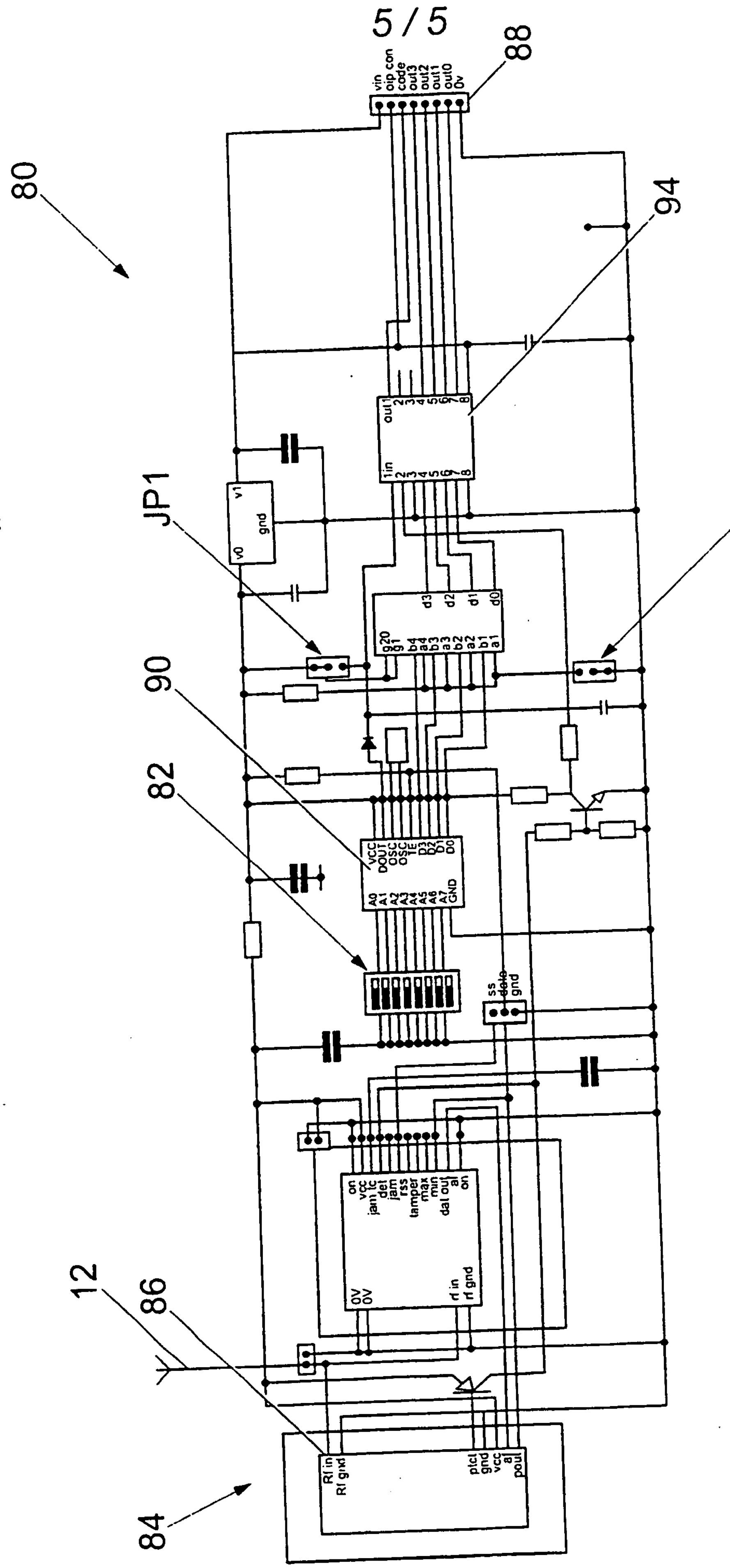
Fig. 4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A1
A2
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vcc
jam tc
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tamper
max
min
dat out
al
on
v0
gnd
v1
g20
g1
b4
a4
b3
a3
b2
a2
b1
a1
d3
d2
d1
d0
1in
out1

Fig. 5

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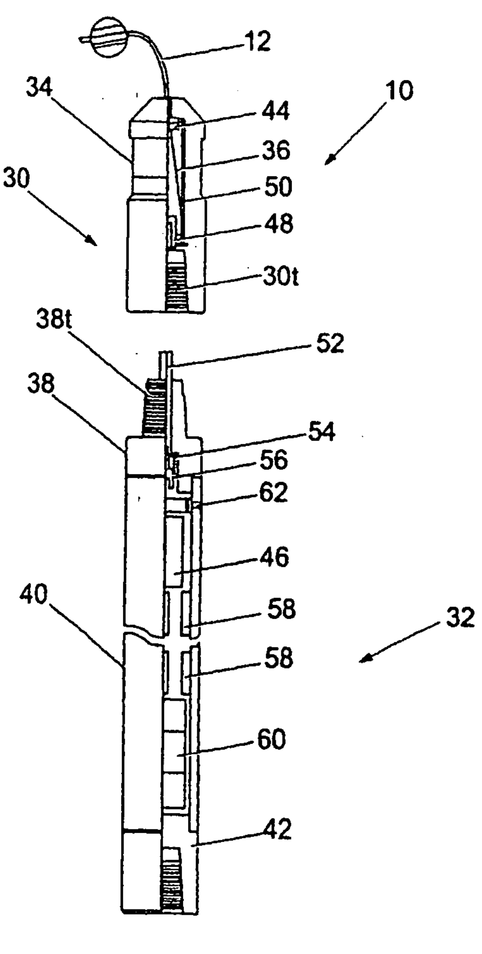
[Continued on next page]

(54) Title: APPARATUS AND METHODS FOR MEASURING DEPTH



(57) Abstract: A communication system for use in a wellbore, a downhole tool, and a method includes a transmitter coupled to a wireline, and a receiver located remotely from the transmitter. The wireline is capable of acting as an antenna for the transmitter. The wireline is a slickline, and the transmitter may be associated with, provided on, or an integral part of a downhole tool or tool string. The transmitter typically transmits data collected or generated by the downhole tool or the like to the receiver, which is preferably located at, or near, the surface of the wellbore. The wireline is typically provided with an insulating coating. Also, a distance measurement apparatus and a method for measuring the distance travelled by a wireline includes at least one sensor coupled to the wireline, and the sensor is capable of sensing known locations in a wellbore.

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(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:

— *with international search report*

(88) Date of publication of the international search report: 2 August 2001

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 00/03491

A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 E21B47/12 E21B47/04

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 E21B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 4 001 774 A (DAWSON ET AL.) 4 January 1977 (1977-01-04) column 3, line 30 - line 64 column 4, line 19 - line 34	1-13
Y		14,18, 20,23, 29,35
Y	US 4 814 548 A (TRAVERSINO ET AL.) 21 March 1989 (1989-03-21) column 1, line 44 - line 46	14
A	US 3 209 323 A (GROSSMAN) 28 September 1965 (1965-09-28) column 5, line 18 - line 37	1

-/--

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

° Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

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Date of the actual completion of the international search	Date of mailing of the international search report
28 February 2001	06.03.2001

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL – 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Rampelmann, K

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	GB 936 461 A (TROSZT) 11 September 1963 (1963-09-11) page 3, line 27 - line 39 page 3, line 79 - line 91 page 4, line 49 - line 57 claim 1	15-17, 19,22, 24,25, 27,28, 30,32-34
Y		14,18, 20,23, 29,35
X	US 3 267 365 A (BAKER) 16 August 1966 (1966-08-16) column 1, line 29 - line 35 column 4, line 34 -column 5, line 39	15-17, 19,22, 24,25, 27,28, 30,32,34
X	US 3 185 997 A (CARLTON ET AL.) 25 May 1965 (1965-05-25) column 1, line 40 - line 42 column 2, line 32 - line 43 column 2, line 63 -column 3, line 42	15,16, 21,22, 26-28,34
X	US 4 044 470 A (DUFRENE) 30 August 1977 (1977-08-30) column 4, line 35 - line 68	22,24

INTERNATIONAL SEARCH REPORT

International application No.
PCT/GB 00/03491

Box I Observations where certain claims were found unsearchable (Continuation of item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1. ☐ Claims Nos.:
because they relate to subject matter not required to be searched by this Authority, namely:

2. ☐ Claims Nos.:
because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:

3. ☐ Claims Nos.:
because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

Box II Observations where unity of invention is lacking (Continuation of item 2 of first sheet)

This International Searching Authority found multiple inventions in this international application, as follows:

see additional sheet

1. ☒ As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.

2. ☐ As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.

3. ☐ As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:

4. ☐ No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

Remark on Protest

☐ The additional search fees were accompanied by the applicant's protest.

☒ No protest accompanied the payment of additional search fees.

FURTHER INFORMATION CONTINUED FROM PCT/ISA/ 210

This International Searching Authority found multiple (groups of) inventions in this international application, as follows:

1. Claims: 1-14

   Communication system

2. Claims: 15-35

   Downhole depth measurement system

Int. ational Application No
PCT/GB 00/03491

Patent document cited in search report		Publication date	Patent family member(s)	Publication date
US 4001774	A	04-01-1977	NONE	
US 4814548	A	21-03-1989	NONE	
US 3209323	A	28-09-1965	NONE	
GB 936461	A		NONE	
US 3267365	A	16-08-1966	NONE	
US 3185997	A	25-05-1965	NONE	
US 4044470	A	30-08-1977	NONE	